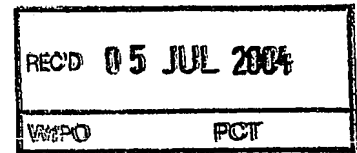




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**Kantutjevning for overlappende projektørbilder**

The invention is used to combine multiple light sources to give the same light intensity and colour as if a single light source was used.

5

This can for instance be used to create a smooth transition between the projected images between two or more projectors. In the overlapping area the projectors must be combined to create the same intensity and colour as if a single projector was used.

10 The use of multiple projectors has been known for a long time. In slide shows more or less overlapping images has been used to provide different visual effects. For these purposes different types of masks have been used to provide the transition between the images. These masks may be sharp edges or define smooth, gradual transitions. By adjusting the masks and the projectors, seamless transitions between adjacent or  
15 overlapping images are provided.

Using video projectors a similar solution is provided in Canadian patent CA 2,025,624 and US 5,136,390, in which the masks are applied electronically. This has, however the disadvantage that the quality of the transitions are dependent on the projectors, as the  
20 projectors' response to input data varies to a large degree between different projectors and with the projector age.

US 6,115,022 describes a related method in which selected parts of the overlapping areas of the images are monitored, both regarding colour and intensity, in real time so as  
25 to secure the image quality in the selected parts. This represents an improvement over the previous solutions but requires more processing while displaying the images and is dependant on selecting relevant parts of the overlapping area.

It is thus an object of this invention to provide a smooth transition between projected  
30 images with built in compensation for colour and intensity variations between the projectors. This is obtained by a method and a device being characterised as described in the independent claims.

The present invention will be explained more in detail below with reference to the accompanying drawings, illustrating the invention by way of example.

Figure 1 illustrates errors in intensity using empirical approximations of the light intensity in the transition area between two projectors.

5 Figure 2 illustrates the mixing of light from two sources.

Figure 3 illustrates the transfer function of a light source.

Figure 4 illustrates two projectors projecting two partially overlapping images on a screen.

10 A projector usually projects 3-4 colour components (red, green, blue and white/clear) for each pixel. Each combination of pixel and colour component can be considered as independent light sources and should be treated separately.

15 A light source has a TF (transfer function), i.e. given an input you get a certain colour and intensity. The TF function can be calculated or measured. The TF might also have other parameters that should be taken into account, e.g. brightness/contrast adjustment capability on a projector. As mentioned above there are individual differences in the TF between projectors e.g. depending on deterioration with age, differences in A/D converters and lamp types.

20

Existing methods for combining light sources to give the same colour and intensity usually has the weakness in that they do not take into account the intensity transfer function, but they create an empirical transition. Figure 1 illustrates the problems related to this solutions, where  $x$  is the position in the edge blending transition between two  
25 images, and  $y$  is the expected intensity divided by actual intensity. As is evident from the drawing several errors may occur. In this example a dark colour  $a$  is too bright in the transition area, while two brighter colours  $c, d$  is too dark in the transition area, even though the empirical approximation was adjusted to a typical colour and the intensity  $b$  is flat as expected.

30

Example: Referring to figure 2 two at least partially overlapping video projectors 1,2 are used for obtaining a combined image 5 from two separate images image 3,4 shown

on separate screens. The system shown in figure 2 comprises a computer or similar storing and controlling the two images 3,4 which are to be combined, and a control unit 6 controlling the projectors 1,2 based on the stored characteristics of each projector. The control unit may comprise per se known means for analysing the projector characteristics, e.g. during start-up, or for receiving such information, e.g. from the computer 7.

Referring to figure 4 the combined image 11,12 have a transition zone 13 where each point is represented by both projectors with chosen intensity and colour. A preferred method will usually be to transition in the overlapping area from one dominating projector to another dominating projector, thus to provide a gradual transition between the two. Each point in the transition zone may be viewed as the mixing of two light sources, two light sources are combined as follows:

$$i_{\text{lightsource1}} = \beta * i_{\text{original}}$$

$$i_{\text{lightsource2}} = (1 - \beta) * i_{\text{original}}$$

- $i_{\text{lightsource1/2}}$  input to the light sources
- $i_{\text{original}}$  original input to the light source before the transition
- $\beta$ ,  $1 - \beta$  – mixing relationship, sums to 1 for all light sources involved (two in this case). Normally  $\beta$  is chosen as  $x/(\text{width}-1)$ , where  $x$  is position in overlap (starting at 0) and width is the width of the overlap in pixels.

The weakness of this method is that it will not give an even light intensity and colour if the TF is not linear and monochromatic. In these cases it is common to create an empirical adjustment, e.g.

$$i_{\text{lightsource1}} = 1^{(T/T)/\gamma} * i_{\text{original}}$$

The formula is as above, but with a parameter ( $\gamma$ ) that is tweaked to get the best possible visual result. This may work reasonably well for a specific value of  $i_{\text{original}}$ , but the

resulting intensity can be too high or low for other input values (See Fig 1). The result is further worsened when the light source does not have a monochromatic TF.

The present invention does not exhibit the abovementioned weaknesses as it takes into account the TF (Fig. 1). For the case above, we have:

$$i_{\text{lightsource1}} = \text{TF}_1^{-1}(\text{TF}_1(i_{\text{original}}) * \beta)$$

$$i_{\text{lightsource2}} = \text{TF}_2^{-1}(\text{TF}_2(i_{\text{original}}) * (1 - \beta))$$

- $i_{\text{lightsource1/2}}$  input to the light sources
- $i_{\text{original}}$  original input to the light sources
- $\beta$  – as above
- $\text{TF}_n(x)$  is the transfer function, as illustrated by figure 3, which evaluates to light intensity and colour for each light source, in this case for an F1 projector from projectiondesign.com.(Photographic mode). Normally the TF is monochromatic, i.e. only the intensity and not the colour changes in response to the input. If the colour as well as intensity changes based upon input,  $\text{TF}_n(x)$  is not a scalar but a vector, normally of size 3. The size of the vector owes its heritage to the eyes ability to distinguish three colours. Ref: tristimulus CIE XYZ in “Computer Graphics – Principles and practice” by Foley, van Dam, Feiner and Hughes, published by Addison Wesley Publishing Company, ISBN 0-201-12110-7.

$\text{TF}_n(x)$  is of arbitrary units such that  $\text{TF}_n(x) = \beta \text{TF}_n(x) + (1 - \beta) \text{TF}_n(x)$ ,  $\beta \in [0,1]$ .

Multiple light sources can be combined and together have a single TF, e.g. projectors with red, green, blue and white components have a single  $\text{TF}(\text{RGB}) = \text{XYZ}$

- $\text{TF}_n^{-1}(x)$  - mathematical inverse of  $\text{TF}_n(x)$ . Sometimes  $\text{TF}_n^{-1}(x)$  is not defined for values of  $x$ , in which case an approximation can be good enough for practical purposes.

If the TF is slightly different for each light source, there will be a smooth transition from the colour and intensity in one source to the colour and intensity in the other light source.

5

In figure 2 and 4 an embodiment of the invention is illustrated in which two projectors 1,2 are used to create a smooth transition 13 between two projectors edge blending. Referring to fig 1, figure 4 shows how a single projected pixel in the overlapping area consists of six independent light sources, red, green, blue from projector 1 and 2

10 respectively. In this case the projectors have the following features:

- Independently controllable colour components, i.e. it can have a white component as long as it is independently controllable. For a projector the white component is not normally independently controllable from the outside and the invention would have to be embedded into the projector.
- the TF varies only in intensity.

15

Each combination of colour component and pixel can in this case be treated separately and in the same manner. Only the light intensity changes in response to the input, hence the transfer functions are actually intensity transfer functions and can be written as:

20

$$ITF_{red/green/blue}(i_{red/green/blue})=intensity$$

Where

25

- $i_{red/green/blue}$  – red, green or blue input value (typically between 0..255)
- intensity – a scalar value between 0..1 when multiplied by  $I_{colormax}$  gives actual colour and intensity
- $ITF_{red/green/blue}(i_{red/green/blue})$  – measured or as in the case of figure 1 given by manufacturer in tabularized form
- $I_{colormax}$  – colour vector for maximum light intensity for colour component.

30

For edge blending we also need to know  $ITF_1^{-1}(\text{intensity})$ .  $ITF_1^{-1}(\text{intensity})$  can be calculated, e.g. using a binary search algorithm on  $ITF()$ , and tabulated.

For a single colour component the input to the projectors to blend a single colour component is calculated as follows:

$$i_{\text{projector}} = ITF^{-1}(ITF(i_{\text{original}}) * \beta)$$

- 10 •  $i_{\text{projector}}$  edge blended color input to the projector
- $i_{\text{original}}$  the input to the projector to show the desired pixel when no edge blending in use
- $\beta$  – mixing factor.  $\beta$  for one projector and  $(1 - \beta)$  for the second. Transitions from 0 to 1 in the overlapping area.

15

Since the edge blending takes place in real time, a practical implementation must be very fast. With a projected resolution of 1280x1024 pixels x 60 Hz, this can be implemented using a modern FPGA (e.g. the Xilinx Virtex-II family). In one embodiment of the invention the following parameters outlines how this was

20 implemented:

- $ITF$  and  $ITF^{-1}$  were implemented as tables with sufficient precision and size to ensure that  $c \approx ITF^{-1}(ITF(c))$
- $ITF$  implemented as a table lookup. 256 entry table of 16 bit integer.
- 25 •  $ITF^{-1}$  implemented as a table lookup. 512 entry table of 8 bit integers
- $ITF(i_{\text{original}}) * \beta$  implemented as (16 bits \* 9 bits integer multiplication)/256
- $\beta$  was decremented from 256 to 0 in the overlap range using mid-section line drawing algorithm

30 If the projectors have red, green, blue and white components, the discussion above still applies, with the exception that there are various complications related to the  $TF()$  of the two identical projectors. The inputs to these projectors are still red, green and blue.

Although each of the red, green, blue and white segments have separate independent TF, they are not separately controllable. The combined TF for all the combined colour components is:

$$5 \quad \text{TF}(\text{RGB}) = \text{XYZ}$$

- RGB – colour input vector to projector
- XYZ – response vector. For practical purposes XYZ are normalized to be in the range [0..1,0..1,0..1]

10

TF(RGB) is in this embodiment either given by manufacturer or measured. This can for instance be done by measuring a large number of samples in the RGB cube and interpolating the rest of the values. E.g. 64x64x64 samples when measured 1 sample/second would take ~ 3 days. With a fast measurement device, e.g. 20 samples a second, 15 it is quite feasible to measure the full range of colours for a projector with 256x256x256 RGB combinations (~10 days). Normally the TF(RGB) is trivially calculated and hence it is preferable to deduce the function or have it provided by the manufacturer.

20

In this case it is non-trivial to find  $\text{TF}^{-1}(\text{XYZ})$  and in some cases it might not even exist, in which case an approximation might be good enough for practical purposes. One method is to use a downhill simplex simulated annealing optimization algorithm, e.g. as described in “Numerical Recipes in C++ Second Edition”, by William H. Press, Saul A. Teukolsky, William T. Vetterling and Brian P. Flannery, published by Cambridge University Press, ISBN 0 521 75033 4), i.e. find RGB such that the expression below is 25 as close to 0 as possible:

$$|\text{ITF}(\text{r,g,b}) - \text{XYZ}|$$

The RGB value to input to the projector to do the blending is then calculated as follows:

30

$$\text{RGB}_{\text{blendedpixel}} = \text{ITF}^{-1}(\text{ITF}(\text{RGB}_{\text{original}}) * \beta)$$

The formula above is not practical to implement in hardware. An alternative is to tabulate the resulted blended colours of the formula above and then interpolating the resulting blended pixel.

- 5 In one embodiment a four dimensional table ( $3 \times 3 \times 3 \times 16$ , RGB $\beta$ ) was created for RGB and  $\beta$  and linear interpolation was used. The size of the table is a compromise between hardware requirements and quality required.

It is practical to implement this blending in hardware using a modern FPGA (2003).

10

One practical aspect of video signals and the TF is signal transmission technology, e.g. an analogue VGA signal is sampled to a digital signal or transmitted digitally using a DVI cable. With a DVI cable, there is no signal loss, but the cable length and bandwidth is more limited than for a VGA cable. If multiple VGA sources are combined as above to a single picture, the errors introduced during the conversion from analogue to digital data can have a substantial negative impact (cable length, slight calibration differences, etc.). Normally it is possible to adjust the A/D conversion to set the 0 level and the dynamic range, frequently described as adjusting brightness (0 level) and contrast (dynamic range). In one embodiment of the solution, a known test image was displayed and the sampled pixel was compared, and based upon this the contrast and brightness for the A/D conversion was automatically adjusted. The reason why the A/D conversion is as critical as when combining multiple images as above is that the TF is very steep, i.e. a small offset/dynamic range error has a large impact on the displayed colour and intensity. The invention therefore also relates to an automatic adjustment method of analogue to digital input video signal conversion using a known input signal and comparing with a resulting digital video signal. This may be obtained by adjusting the zero offset and dynamic range automatically according the result of the comparison.

25

To summarise; the invention relates to a method for combining images from at least two light projectors, the images having a transition zone between them, wherein the dimensions of the transition zone is known, and the emitted light toward the transition zone from each projector is based on a predetermined transfer function from input

30

signal to projected image for each projector in the transition zone, so as to obtain predictable image characteristics in the transition zone.

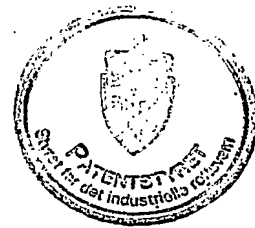
5 The transition zone may be, as illustrated in figure 2, the overlapping parts of two adjacent images. It is, however, clear that the transition zone may be of different types and shapes, e.g. if an image from one projector is surrounded by the image from another projector.

10 As stated above the method according to the invention may comprise the step of interpolating between the light characteristics of a first projector to the light characteristics of a second projector over the image transition zone area, so as to provide a smooth transition between the projected images. In most cases the transition zone is the same as the overlapping part of the images, but other situations may be contemplated, e.g. in the transition between adjacent, non-overlapping images. This  
15 may apply if there are large differences between two projectors and the interpolation requires a smoother transition than available in a small overlapping area. This is of course limited by the available variations in the projectors intensity and colour room.

20 Also as stated above the transfer function may be calculated from known characteristics of the projector or measured by providing a known signal to the projector, measuring the emitted light and calculating the transfer function from the measured relationship between applied signal and measured light characteristics. The applied signal may be a ramp from zero output intensity to full output intensity of the projector, a process which may be performed as an automatic part of the start up procedure of the system and  
25 projectors.

The control device according to the invention for at least two image projectors being adapted to project overlapping images at a surface and defining a transition zone between the images from each projector, the device comprising memory means for  
30 storing a transfer function for each projector, said transfer function describing the relationship between input signal and emitted light of each projector, and calculating means for applying said transfer functions on said input signal so as to obtain a

predictable image characteristics in the transition zone between the at least two projected images.



C l a i m s

1. Method for combining images from at least two light projectors, the images having a transition zone between them,  
wherein the dimensions of the transition zone is known, and the emitted  
5 light toward the transition zone from each projector is based on a predetermined transfer function from input signal to projected image for each projector in the transition zone, so as to obtain predictable image characteristics in the transition zone.
2. Method according to claim 1 wherein the transfer function is obtained by  
10 measuring the relationship between the input image data and the characteristics of the emitted light.
3. Method according to claim 1, wherein the light characteristics of the emitted light also includes the colour characteristics the light.
- 15 4. Method according to claim 1, wherein the transfer function is applied to input data to the projector so as to condition the data to obtain the required image characteristics.
- 20 5. Method according to claim 1, comprising the step of interpolating between the light characteristics of a first projector to the light characteristics of a second projector over the image transition zone area, so as to provide a smooth transition between the projected images.
- 25 6. Method according to claim 1, wherein the transfer function is determined by known signal to the projector, measuring the emitted light and calculating the transfer function from the measured relationship between applied signal and measured  
light characteristics.
- 30 7. Method according to claim 6, wherein the applied signal is a ramp from zero output intensity to full output intensity of the projector.

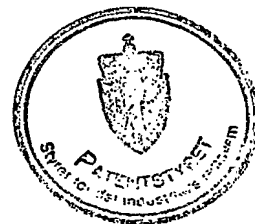
8. Method according to claim 6, wherein the transfer function is measured and calculated as an automatic part of the projector start up procedure.

5 9. Control device for at least two image projectors being adapted to project overlapping images at a surface and defining a transition zone between the images from each projector, the device comprising memory means for storing a transfer function for each projector, said transfer function describing the relationship between input signal and emitted light of each projector, and calculating means for applying said transfer functions on said input signal so as to obtain a predictable image characteristics in the  
10 transition zone between the at least two projected images.

10. Automatic adjustment method of analogue to digital input video signal conversion using a known input signal and comparing with resulting digital video signal.

15

11. Method according to claim 10, wherein the zero offset and dynamic range is adjusted automatically.



**Abstract**

Method and device for combining images from at least two light projectors, the images having a transition zone between them, wherein the dimensions of the transition zone is known, and the emitted light toward the transition zone from each projector is based on a predetermined transfer function from input signal to projected image for each  
5 projector in the transition zone, so as to obtain predictable image characteristics in the transition zone.

**Figure 2**

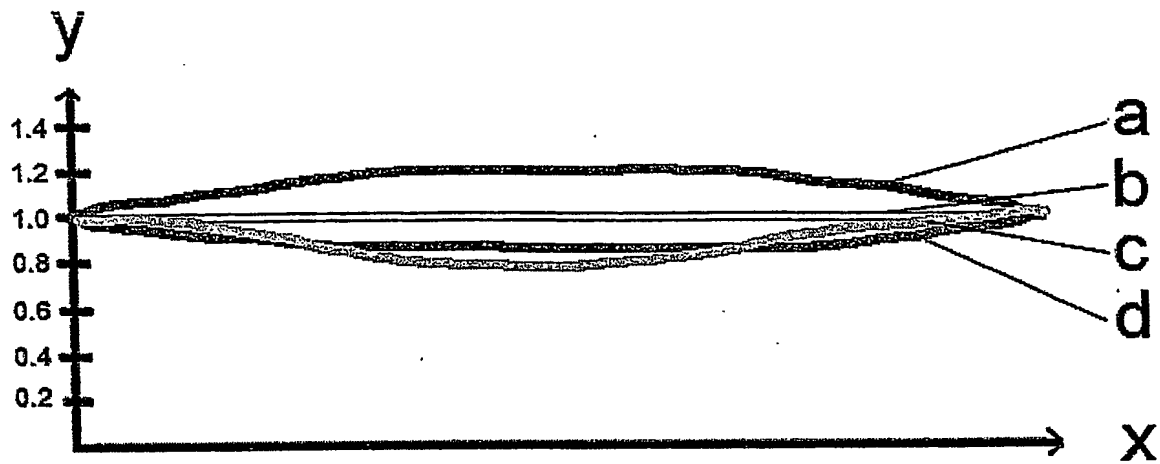


Fig. 1

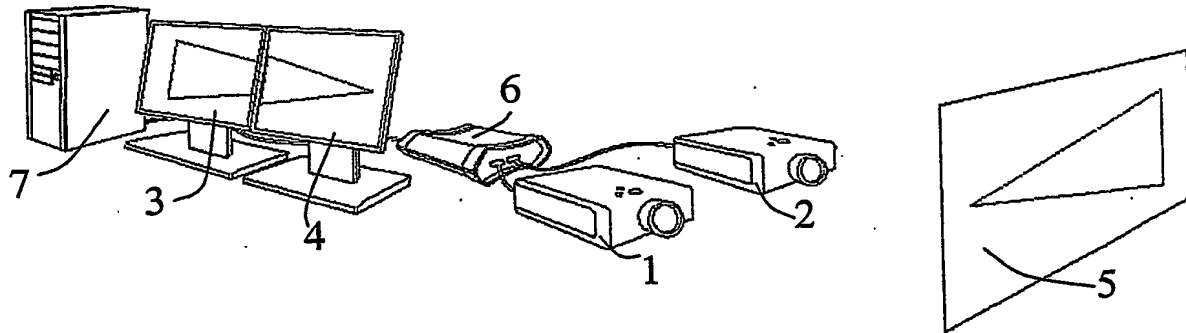


Fig. 2



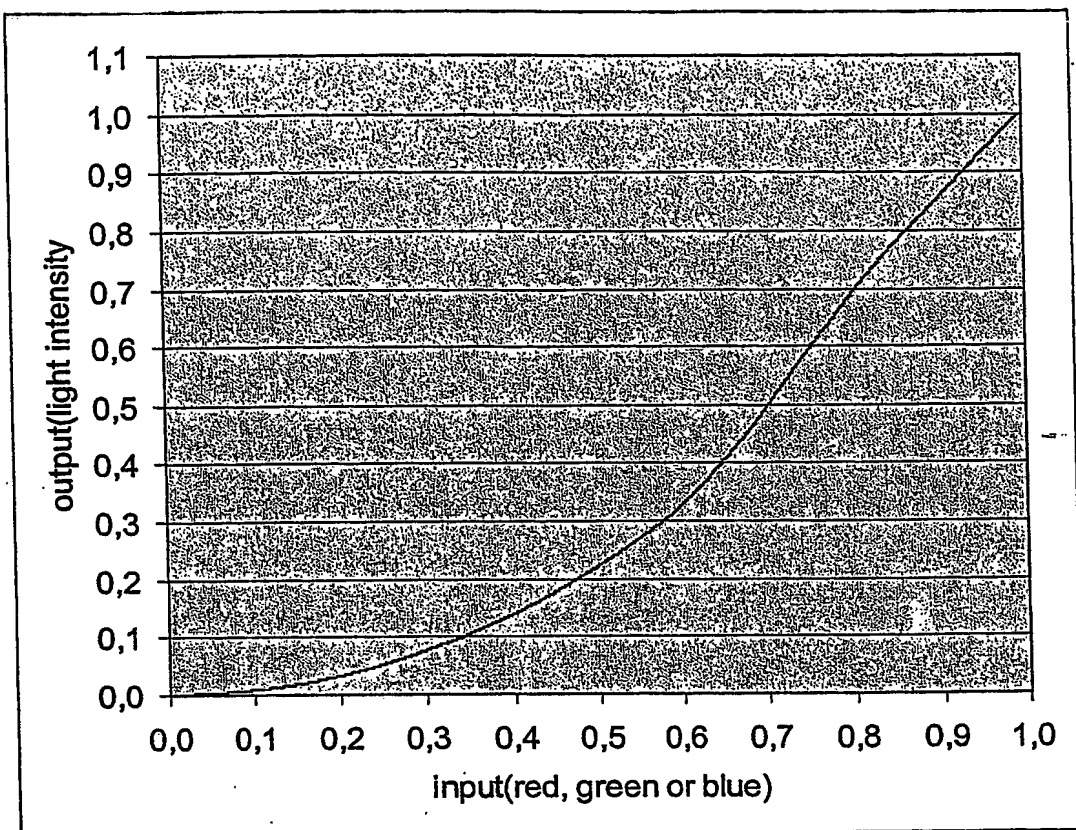
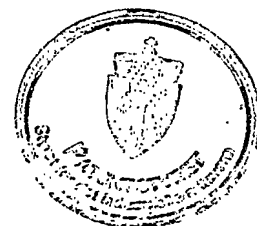


Fig. 3



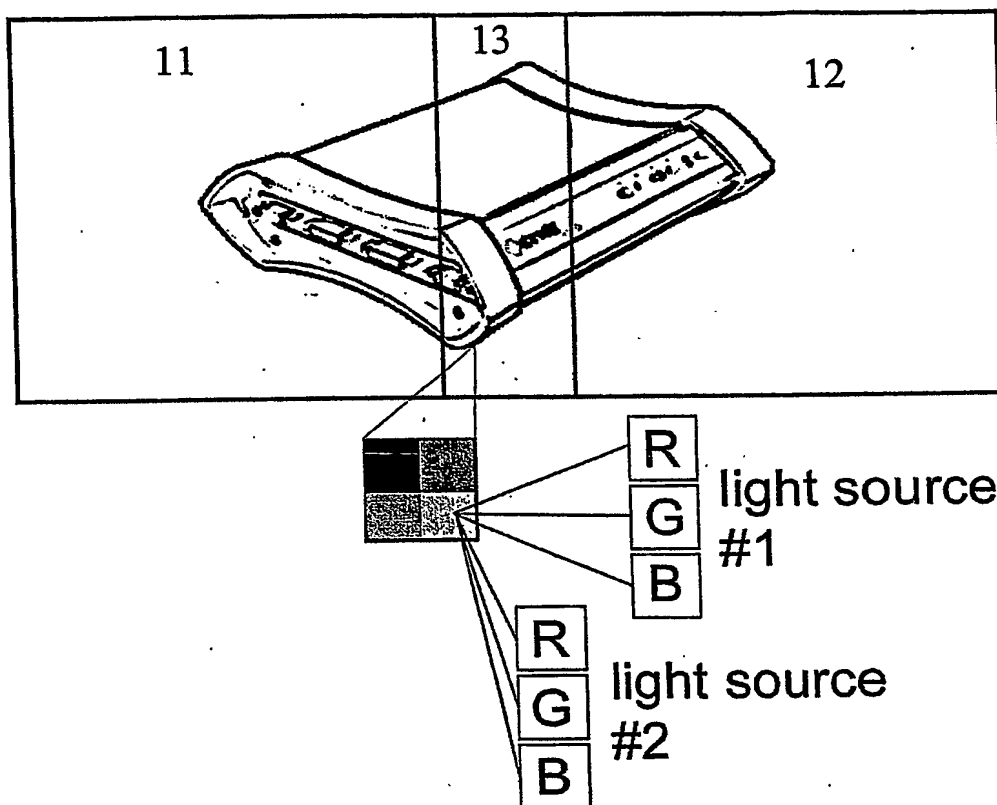
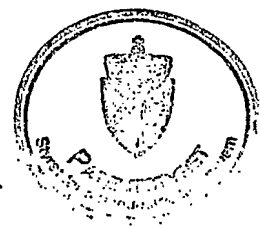


Fig. 4



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